NOAA Research Review Information
Climate Monitoring and Diagnostics Laboratory
Dave Hofmann – February 6, 2004

Question 1: Most recent evaluation of NOAA/CMDL.

An evaluation of CMDL was conducted in May 2002 by an external review panel selected by OAR and approved by the NOAA Science Advisory Board (SAB). Two members of the SAB participated on the Review Panel. A Program Review document was prepared for the Review Panel prior to the review. It is attached as a pdf file. The Review Panel's report, also attached, (CMDL-SAB-Review-Report2002Jun21.pdf), was presented by a member of the review Panel to the SAB at a meeting in July 2002 and the Review Panel's recommendations were endorsed by the SAB (letter attached). The SAB was briefed on OAR's response to the recommendations at a meeting in July 2003, (briefing attached). This was the first and thus far only such SAB-approved review of an OAR Laboratory; thus all the pertinent documents have been included.

Question 2: Brief history, and mission of NOAA/CMDL.

History. CMDL was formed in 1990 from climate-related elements within the Boulder branch of the ERL Air Resources Laboratory, in particular, the Geophysical Monitoring for Climatic Change (GMCC) program and the Climate Research Division (CRD). The latter became the Climate Diagnostics Center (CDC) in 1993. Four of the Baseline Observatories (Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and South Pole Station, Antarctica), are manned by NOAA employees and were established shortly after NOAA's creation in the early 1970's. A fifth observatory, serviced by Humboldt State University employees, was established at Trinidad Head, California in 2002 in order to monitor Asian emissions incident on the west coast of the U.S. In recent years, substantial improvements have been made at the Observatories including major building projects at Mauna Loa, South Pole (in collaboration with the National Science Foundation) and are being planned at the Barrow Observatory. The current staff of CMDL includes 50 federal employees and 34 non-federal employees of which about 30 are Joint Institute (University of Colorado, Cooperative Institute for Research in the Environmental Sciences) scientists and engineers.

Mission. The Climate Monitoring and Diagnostics Laboratory (CMDL) is the only federal laboratory whose mission is to monitor atmospheric greenhouse species that affect climate and those that cause ozone layer depletion. Long-term, continuous, precise measurements of climate forcing and ozone layer depleting species are required for climate and ozone layer projections which are delivered to customers through international assessments such as the IPCC Climate Assessments and the WMO/UNEP Ozone Assessments. Linkage to the NOAA Strategic Plan is through Mission Goal 2: *Understand climate variability and change to enhance society's ability to plan and respond.* CMDL's research is linked closely to the U.S. Climate Change Science Program which has as its Mission Goal 2: *Improve the quantification of the forces bringing about changes in the Earth's climate and related systems*, which has been adopted for the NOAA Climate Program Mission Goal 2. CMDL accomplishes its mission through five Baseline Observatories and a global cooperative flask sampling network. Climate forcing species

monitored include carbon dioxide and methane and their isotopic carbon content, nitrous oxide, the CFCs, stratospheric and tropospheric ozone, aerosols, solar radiation, and for stratospheric ozone depletion, all the chlorine- and bromine-bearing species that deplete ozone. CMDL's data are available on the CMDL web site: http://www.cmdl.noaa.gov/info/ftpdata.html

Question 3. Listing of major customers of CMDL and what is done for them.

The customers for CMDL products are many and varied, ranging from international organizations through governmental agencies and universities, to a wide selection of individuals obtaining information and data on various aspects of atmospheric composition, climate forcing, trends in trace gas concentrations, and the state of the ozone layer. CMDL's climate forcing and ozone-depleting gas sampling and analytical networks are the largest and most comprehensive, and among the most precise and accurate in the world. Below is information on the lab's customer base ordered by the products CMDL delivers.

A. Support of research and atmospheric monitoring at the manned CMDL Baseline Observatories at Pt. Barrow, Alaska; Trinidad Head, California; Mauna Loa, Hawaii; American Samoa; and South Pole, Antarctica; at a variety of cooperative programs around the world, and from programs operated through the CMDL Boulder facilities.

In addition to the hundreds of measurement programs that CMDL scientists conduct within the global observation network, CMDL also supports or cooperates in measurement programs and supplies data to research and operational programs throughout the U.S. and the world. These include the following:

- U.S. Federal Agencies such as DOE, DOD, EPA, USDA, FAA, NSF, NASA, USGS, State Department and 10 NOAA laboratories and Joint Institutes (34 programs)

- Universities within the United States such as Stanford, U. of Alaska, Harvard, Scripps Institution of Oceanography, Princeton, Caltech, Colorado State, SUNYA etc. (66 programs)

- State and local agencies (26 programs)

- International universities, national meteorological services, and foreign research agencies (48 programs)

At South Pole Station, CMDL partners with the NSF Office of Polar Programs in operating the NOAA Clean Air Facility in the Atmospheric Research Observatory.

B. Long-term atmospheric constituent data records from a combination of continuous measurements at the Baseline Observatories and cooperative measurements from 68 sites around the globe are used by CMDL to produce the most high quality, long-term records of atmospheric change available on earth. These data records are used by scientists to explain changes in the ozone chemistry of the atmosphere, to monitor atmospheric aerosol loadings, to study the global carbon cycle, and to examine the radiative balance of the atmosphere. CMDL data were used by

the United States and foreign governmental agencies in helping to determine the cause of the Antarctic Ozone Hole, as support for the implementation of the Montreal Protocol controlling CFCs and other ozone-depleting compounds, and is used to assess the efficacy of the international controls on the production and release of ozone-depleting gases. Records of global carbon dioxide trends, obtained at the Mauna Loa and South Pole Observatories since 1957, are considered by many scientists to be one of the most important geophysical records of current times. Rising carbon dioxide levels formed the basis for global atmospheric warming scenarios.

About 85% of the world's carbon dioxide data are derived from CMDL's Cooperative network. CMDL has compiled these global carbon dioxide and methane data together with data from other countries to form global greenhouse gas data bases (GLOBALVIEW-CO_2 and GLOBALVIEW-CH_4 - http://www.cmdl.noaa.gov/ccgg/globalview/index.html). To date, GLOBALVIEW has been cited in 55 refereed scientific papers and between March and November 2003 there were 6511 downloads of GLOBALVIEW data sets from 50 different countries. Recently an Interactive Atmospheric Data Visualization (IADV) program has been added to CMDL's web site (http://www.cmdl.noaa.gov/ccgg/iadv/). The IADV web site allows researchers to (1) view near real-time CMDL measurements of CO_2, CH_4, CO, H_2, N_2O, SF_6, and the isotopic composition of CO_2 and CH_4; (2) obtain details about each sampling location, (3) manipulate and compare data sets, (4) create custom graphs, and save them in a variety of formats. The web site allows a visual display of how gases change with time, for example the actual global CO_2 distribution can be observed as it goes through its annual cycle from 1990 through 2002. These features make the data product useful for non-specialists and students as well as scientists.

C. International Standards and Facilities such as the WMO trace gas standards for carbon dioxide, carbon monoxide, nitrous oxide and methane, that are used by numerous research and monitoring groups across the United States, are produced and supplied by CMDL to 13 nations. CMDL maintains the world standard Dobson spectrophotometer for total column ozone measurements and provides column ozone calibrations for 31 countries. CMDL maintains the historical International IR irradiance (greenhouse) radiation standard and is the solar radiation calibration facility for WMO Region 4. CMDL also manages and contributes data to the global Baseline Surface Radiation Network (BSRN) for the World Climate Research Program (WCRP). BSRN will soon become a part of the Global Climate Observing System (GCOS). CMDL's Mauna Loa Observatory is the site of a Network for the Detection of Stratospheric Change (NDSC) primary station. Numerous remote sensing instruments provided by CMDL and other agency scientists are used to detect the chemical change of the stratosphere with a primary goal of monitoring the health of the ozone layer.

D. International Scientific Assessments, such as the IPCC Assessment on Climate Change and the WMO/UNEP Scientific Assessment of Ozone Depletion are contributed to by CMDL scientists through section authorship, and through data and scientific analyses. In the previous 5 IPCC Assessment Reports, CMDL publications and data sets were cited at least 276 times while for stratospheric ozone-related work, CMDL publications and data sets were cited 223 times in the 1998 and 2002 WMO/UNEP assessments.

E. Publications in refereed journals with extramural partners in which CMDL's data are used is a good measure of the importance of these data products. In the past five years at least

189 publications of analysis of CMDL data with joint extramural and CMDL authorship have appeared in scientific journals including Science, Nature, Journal of Geophysical Research, Tellus, and Geophysical Research Letters, among others.

Question 4. Summary of research being conducted.

CMDL's research involves the monitoring and analysis of atmospheric composition data (including carbon cycle and other trace gases, aerosols and radiation) obtained at five Baseline Observatories and through its global cooperative network at over 60 sites. CMDL also has a small element in NOAA's Weather and Water program under monitoring Baseline Air Quality, focusing on Asian emissions incident on the U.S. west coast at the Trinidad Head Observatory in California. CMDL also develops new measuring instruments, mainly through NASA funding for stratospheric aircraft and balloon campaigns. These new instrument designs, such as gas chromatographs and mass spectrometers, find application at CMDL field sites, thus allowing CMDL to remain at the forefront in atmospheric species measurement.

CMDL contributes to all of NOAA's four strategies (Monitor and Observe, Understand and Describe, Assess and Predict, and Engage, Advise and Inform), as reported in the FY06 Program Baseline Assessment for the Climate Forcing component:

Capability (1) **The ability to globally monitor the climate-forcing gases and characterize key aerosol properties.** Specifically, to be able to monitor the changes in the global abundance of atmospheric and oceanic carbon dioxide, atmospheric water vapor, the radiatively-important trace species, and the ozone-depleting gases, in collaboration with Climate Program Component 1.

Capability (2) **The ability to understand the processes that cause climate forcing.** Specifically, to have the ability to discover and characterize (i) the atmospheric and oceanic processes that influence the global carbon cycle and (ii) the atmospheric roles of the radiatively-important and ozone-depleting trace species.

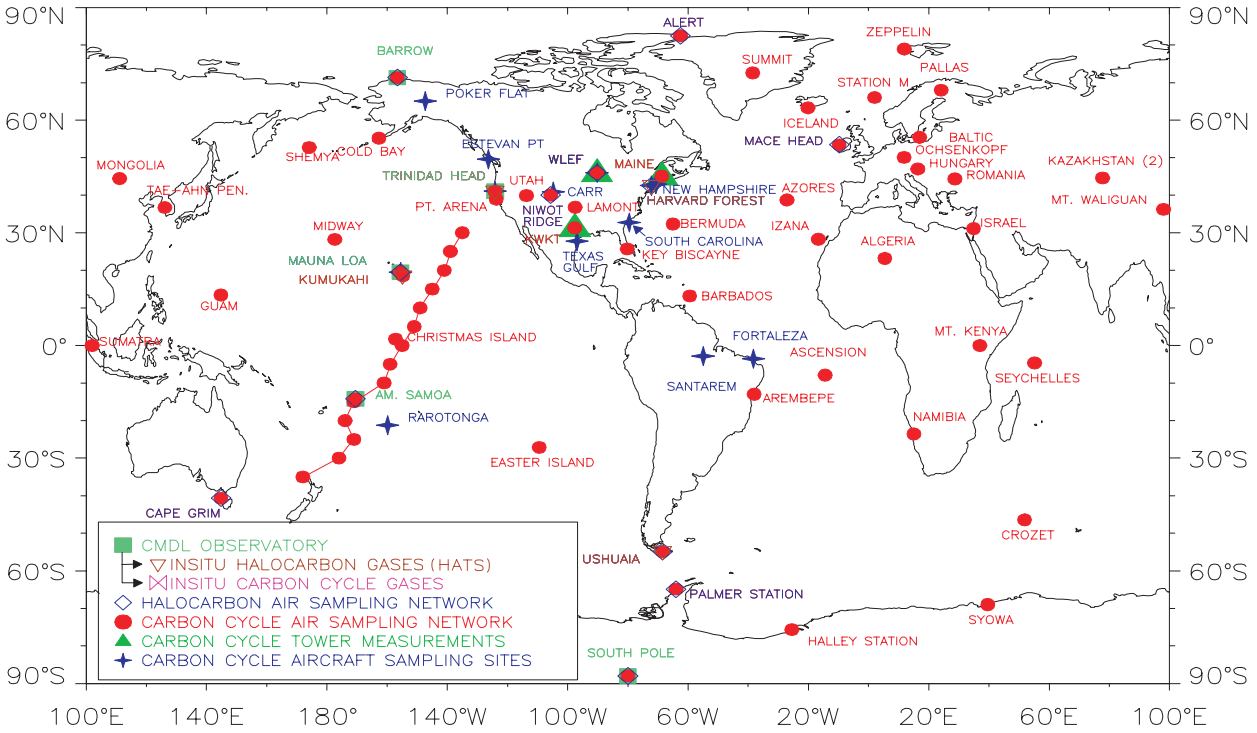
Capability (3) **The ability to characterize observations for input to climate models.** Specifically, working with Climate Program Component 3, analyze and diagnose observations to formulate the information on the radiative forcing so that global climate models can better simulate the role of human activities.

Capability (4) **The ability to deliver to stakeholders the needed information on radiative forcing of climate.** Specifically, in partnership with the other Climate Program Components, to be able to provide the mutually agreed-upon information on the radiatively important gases and aerosols that is needed to support policy decisions related to climate change, carbon management, and ozone-layer recovery.

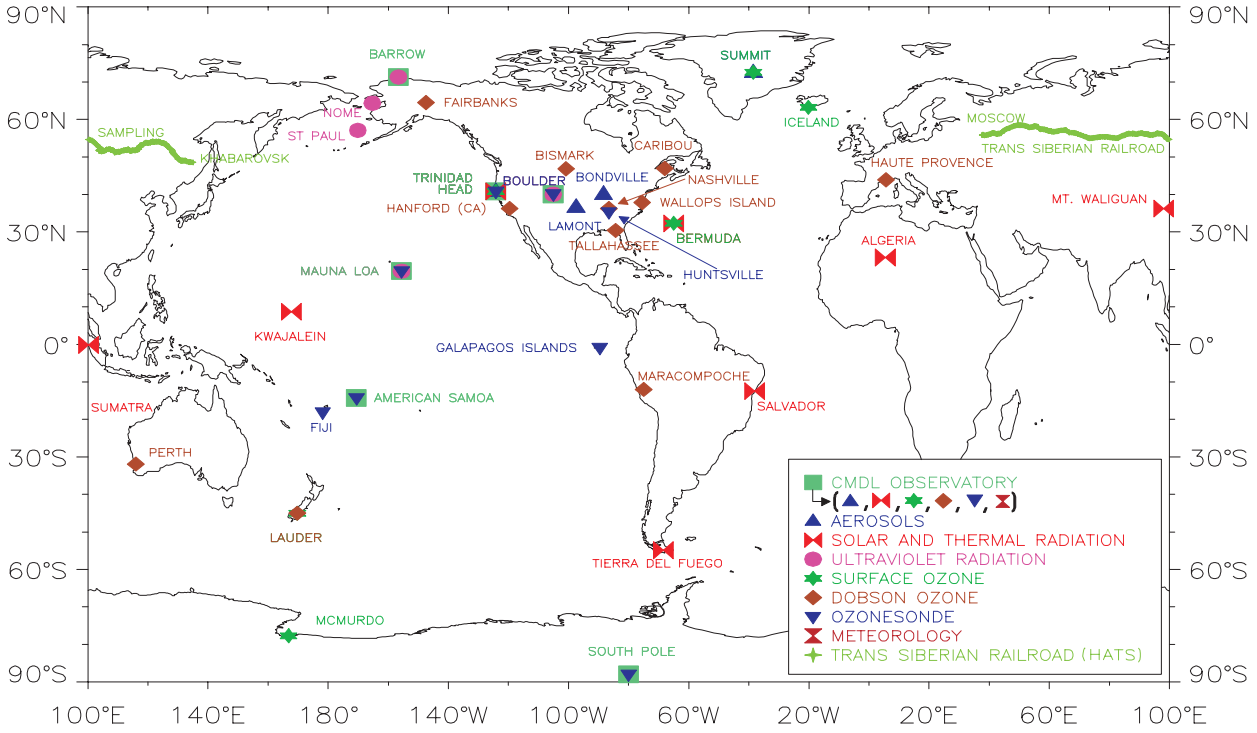
The geographical scope of CMDL monitoring and research is best summarized in the following figure showing sites of CMDL and CMDL cooperative measurements. All of CMDL's research is classified as long-term (greater than five years).

NOAA/CMDL Monitoring Sites

CMDL Carbon Cycle and Halocarbon Gases



Ozone, Aerosols, Solar Radiation, and Meteorology



Within North America, the number of aircraft and tall tower carbon cycle measurement sites is scheduled to triple by 2007. This expansion is part of the interagency North American Carbon Program (NACP), with a goal to better characterize the magnitude and variability of the North American carbon sink, a short-term (2-4 years) U.S. CCSP synthesis product. Table 1, from the recently drafted NACP Implementation Plan, shows the planned distribution of North American aircraft sites (of which nine have been implemented by CMDL to date). Funding for the program is through the Climate Change Research Initiative's Carbon Cycle Atmospheric Observing System element which included $2.5 M in FY04 and $6.5 M which is in the President's budget for FY05.

Table 1. Summary of Aircraft Sites and Sampling Frequency

Site[a]		Sampling Frequency (days)				
##		FY02	FY03	FY05	FY07	Other Measurements
01	*Harvard Forest,MA*[b]	30	14	7	7	*flux, cont. CO_2*
02	*Carr, CO*	7	7	7	7	--
03	*Tofino, BC*	0	7	7	7	*flask (Estevan Point)*
04	*Park Falls, WI*	30	7	3.5	3.5	*flux, flask, cont. CO_2 (LEF)*
05	*Fairbanks, AK*	30	7	7	7	--
06	Trinidad Head, CA	0	7	7	7	CMDL observatory
07	Corpus Christi, TX	0	7	7	7	tower = Moody (WKT)
08	Portsmouth, NH	0	3.5/7[c]	3.5	3.5	--
09	New Bern, NC	0	7	3.5	3.5	(tower = Grifton)
10	Ames, IA	0	0	3.5	3.5	(tower)
11	Ponca City, OK	0	0	3.5	3.5	flask, cont. CO_2 (SGP)
12	Bermuda	0	0	7	7	flask (BME, BMW)
13	Mt. Vernon, IL	0	0	3.5	3.5	--
14	Devil's Lake, ND	0	0	3.5	3.5	(tower)
15	Alliance, NE	0	0	3.5	3.5	(tower)
16	Mansfield, OH	0	0	3.5	3.5	(tower)
17	Pellston, MI	0	0	3.5	3.5	(tower)
18	Savanna, GA	0	0	3.5	3.5	--
19	St. Johns, NL	0	0	7	7	--
20	Barrow, AK	0	0	0	7	CMDL observatory (BRW)
21	Nome, AK	0	0	0	7	--
22	Sitka, AK	0	0	0	7	--
23	San Diego, CA	0	0	0	7	Scripps Pier (SIO)
24	Elko, NV	0	0	0	3.5	flask (UTA)
25	Midland, TX	0	0	0	3.5	(tower)
26	Las Cruces, NM	0	0	0	3.5	--
27	Morgan City, LA	0	0	0	7	--
28	El Dorado, AR	0	0	0	3.5	(tower = Jonesboro)
29	Huntsville, AL	0	0	0	3.5	(tower = Selma)
30	Chambersburg, PA	0	0	0	3.5	(tower)
31	Lewistown, MT	0	0	0	3.5	(tower)
32	Richland, WA	0	0	0	3.5	--
33	Yellow Knife, NT	0	0	0	3.5	--
34	*Prince Albert, SK*[b]	0	0	0	3.5	flux, cont. CO_2 (BERMS)
35	*Thompson, MB*[b]	0	0	0	3.5	flux, cont. CO_2 (NOBS)
36	Fraserdale, ON	0	0	0	3.5	flask, cont. CO_2
37	Labrador City, NL	0	0	0	3.5	--

Notes: *Italicized sites are in operation as of December 2002.*

[a]Site selection is subject to NACP Science Team planning

[b]Data specifications pending for inclusion of flux tower measurements in the global data base.

[c]Sample once or twice per week on alternate weeks

Question 5. Major Accomplishments in the last five years.

Research at CMDL is unique in that the scientific questions being explored directly address long-term global issues such as climate forcing, ozone depletion, and baseline air quality. Minute changes in these quantities over long periods of time require consistently precise measurement and scientific scrutiny of the data on a continual basis. Questions concerning the effects of climate change and the mitigation of impacts are of utmost importance to society and policy-makers. They can be resolved only by making, preserving, and interpreting high-quality, long-term, continuous observations using comprehensive, scientifically designed, sampling networks. Dedication to such careful, precise, measurements over the long term has resulted in a number of critical discoveries which would not have occurred without the inseparable blend of research and operations inherent in CMDL's mission. Examples are the following brief summaries of major accomplishments by CMDL scientists, utilizing CMDL monitoring network data.

1. Identification of the Northern Hemispheric Terrestrial Carbon Sink; Underpinnings of the North American Carbon Program ***(U.S. Department of Commerce Gold Medal Award, 2000)***

CMDL scientists established and maintained over the past few decades the world's largest, most comprehensive, precise, and accurate network for the measurement of CO_2 and other climatically important atmospheric trace gases. Latitudinal gradients of CO_2 from this network identified a "missing" carbon sink as being in the northern hemisphere and from isotopic analysis established that it was related to the terrestrial biosphere. Inverse transport modeling using CMDL data indicated that North America is a CO_2 sink that may rival the national emissions of CO_2 from burning of fossil fuels in some years. This observational and scientific program provided a portion of the impetus for the U.S. Carbon Cycle Science Plan and the North American Carbon Program, which focuses on improving our understanding of how this removal of CO_2 from the atmosphere occurs. Because carbon-based fuels underpin our entire energy system, the social and economic implications of this work are huge. In guiding our future, policy-makers must be able to weigh options based upon the best available science. Because of its policy-relevant importance, the U.S. Climate Change Science Program (CCSP) has made the North American carbon sink issue one of its short-term deliverables (synthesis products).

2. Documenting the Rise and Decline of Ozone-Depleting Compounds in the Global Atmosphere. ***(Department of Commerce Silver Medal Award, 1997; NOAA/OAR Outstanding Scientific Paper awards 1996; 1998 (2); 1999 (2))***

CMDL scientists published the first and a subsequent series of papers on the global atmospheric distributions of stratospheric ozone-depleting halogen compounds such as the chlorofluorocarbons and bromine-containing gases. These publications were based upon the unique, long-term measurements made globally by CMDL and underscore the significance of human activities in the rise, prior to 1994, and now the decline of these gases in the atmosphere. These results stress the importance of continued adherence to emission reduction requirements of the U.S. Clean Air Act and the international Montreal Protocol in order for these downward trends to continue. Reversing the trend in ozone depletion has the potential to measurably improve the health of human populations and natural ecosystems; doing so requires continued

high-quality observation, analysis, and assessment by scientists invested in understanding these processes.

3. Discovery and Documentation of the Increase in Stratospheric Water Vapor ***(NOAA/OAR Outstanding Scientific Paper Award, 2002).***

CMDL's balloon-borne observations at Boulder, Colorado, led to the discovery and documentation of the increase of water vapor in the stratosphere (of the order of 1 % per year for the past 20 years). This observational record constitutes the longest, continuous measurement of stratospheric water vapor, a gas that is implicated in ozone depletion, stratospheric chemistry, and climate forcing, and is believed to be representative of northern midlatitudes globally. National and international scientific assessments of ozone and climate change have cited this work as fundamental to determining the role of stratospheric water vapor in ozone depletion and climate change. The source of this increase is only partially related to the oxidation of methane (which until lately has been increasing) in the stratosphere; the remaining source is unknown but is likely related to a regime shift in climate or atmospheric dynamics. Our understanding of this and other trends has direct bearing on important policy decisions relevant to reducing or mitigating human impacts on the earth's climate.

4. Documenting the Decline in the Growth Rate of Global Atmospheric Methane ***(Department of Commerce Bronze Medal, 1998; NOAA/OAR Outstanding Paper Awards, 1995, 1998, 2001)***

CMDL scientists published a series of timely and significant reports on the global distribution and growth rate of atmospheric methane, a gas that is implicated in both climate forcing (second in importance to CO_2) and ozone depletion (reacts with chlorine compounds related to ozone depletion). Key findings include the first report of a slowdown in the growth of atmospheric methane concentrations and a proposal that the cause was related to a relatively short-lived (lifetime of about 9 years) gas approaching a balance in sources and sinks. This contention was supported by a later report of the observations showing that atmospheric concentrations of this gas had ceased to increase, and most recently, a report that the global burden had stabilized from 1999-2002, somewhat earlier than had been predicted from the equilibrium model proposed earlier. These published reports have put substantial constraints on the global methane budget and significantly enhanced our understanding of the global behavior of the gas. This research provides information necessary for science-based decisions related to mitigation of future impacts of methane on climate.

5. Identification of the Non-Volcanic Background Stratospheric Aerosol

Sulfuric acid aerosols, which form in the stratosphere from volcanic and surface-based pollutant sulfurous gases, accelerate ozone depletion by increasing the surface area available for heterogeneous chlorine catalyzed reactions, and also directly force a cooling of the earth's atmosphere through backscattering solar radiation. Aerosol particles from major volcanic eruptions cause a forcing in the lower atmosphere of about a negative 4 Wm^{-2}, more than twice as large, and of opposite sign, as the forcing related to the post-industrial CO_2 increase, lasting for 1-2 years and having a measurable transient effect on climate. The question of whether a

stratospheric sulfate aerosol layer could exist in the absence of major volcanic eruptions had not been answered until recently. Following the total decay of aerosol from the 1991 Pinatubo volcanic eruption, which took until about 1996, no major eruptions capable of perturbing global stratospheric aerosol levels have occurred. During this unprecedented period, CMDL scientists were able to study and evaluate the behavior of stratospheric aerosol over the Mauna Loa Observatory in Hawaii, in an attempt to assess the relative contributions of natural and human-driven processes to this climatically important feature of the stratosphere. The study shows that natural sulfurous gases cannot account for the background stratospheric aerosol and that human contributions of sulfur, such as occur in fossil fuel combustion, must be significant. This information allows for a better assessment of the climatic impacts of mainstream and alternative energy use, a needed element for future energy-policy decisions

6. Summary of legal mandates for the work in CMDL (from the Program Baseline Assessment, Climate Program Goal 2 – Climate Forcing.)

- *Public Law 95 – 95, Clean Air Act Amendments, 1990.* NOAA (and NASA) is required to "… continue programs of research, technology, and monitoring of the phenomena of the stratosphere for the purpose of understanding the physics and chemistry of the stratosphere and for early detection of potentially harmful changes in the ozone in the stratosphere …" Further, NOAA (and NASA) is required to report "… on the current average tropospheric concentration of chlorine and bromine and on the level of stratospheric ozone depletion."

- *Framework Convention on Climate Change* (FCCC, 1992*).* The United States is one of 36 countries that signed the United Nations Framework Convention on Climate Change. In addition to its objective of "... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.", the convention requires its Parties to conduct research and systematic observation to provide the scientific decision support. The NOAA Climate Forcing Program addresses that commitment by the U.S., e.g., science-vetted climate-change scenarios that can help policy decisions associated with what is "dangerous interference".

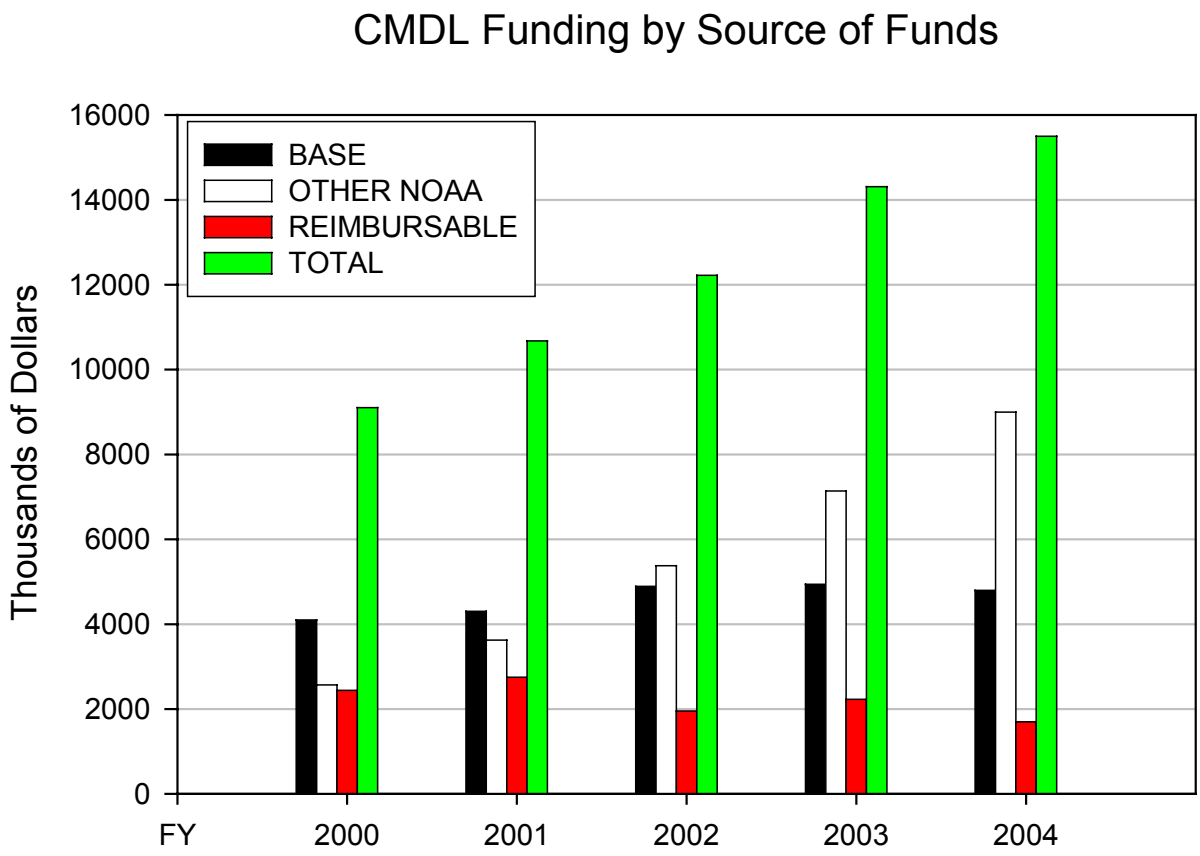
- *Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP, 2003). The United States is one of many Parties to the Vienna Convention (1985) and its Montreal Protocol (1987). The Protocol established three assessment panels to provide scientific, technical, and economic information every four years to support the Parties in their decisions for the protection of the ozone layer. This four-year deliverable is a key information product of the U.S. Climate Change Science Program. It is a guiding focus for the planning and carrying out of the research of the Program.

7. Financial data as shown in the Excel spreadsheet should be as follows:

CMDL Funds – FY2003:

Permanent Base:	$ 4.94 M
Other NOAA:	7.14 M
Non-NOAA:	2.23 M
TOTAL:	$14.31 M

CMDL funding in recent years (FY2004 – estimated) is summarized in the figure below:



Contact persons: Dave Hofmann 303-497-6966 and Russ Schnell 303-497-6733